Risk Assessment of Sensory Irritants in Indoor Air – A Case Study in a French School

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Key Words

airborne sensory irritants; exposure; mixtures; risk assessment; weighted sum parameter

Abstract

Exposure to airborne pollutants can result in adverse health effects. Acute symptoms can for instance comprise of irritation of the eyes or of the respiratory tract (called sensory irritation). In a recent case, health problems were reported in a French school and supposedly attributed to the presence of airborne irritant pollutants. Based on measured concentrations, the risk of developing the described health effects was assessed. Numerous airborne sensory irritants (aldehydes, organic acids, VOCs, SO_2, NH_3) were identified and quantified in the indoor air by using active and passive sampling and online monitoring techniques. Reference values based on toxicological properties of compounds (sensory irritants) were taken from the literature. If not available, tentative values were specially developed for this purpose. Concentrations of all sensory irritants remain below their corresponding guideline values and are comparable to literature data. It was concluded that the risk of developing sensory irritation due to the presence of the studied compounds is negligible. This holds both for individual compounds and for the mixture

of studied compounds. Limitations of the employed sampling strategy, and of existing sampling and analytical techniques, which do not allow for analysing more reactive compounds – which are strong sensory irritants – may play a role. New sampling techniques need to be developed. Psychosocial factors (group behaviour, increased attention to sensory irritation) should also be taken into account when dealing with health complaints on sensory irritation.

1. Introduction

Exposure to airborne pollutants can result in adverse health effects. Acute symptoms may for instance comprise of irritation of the eyes or of the respiratory tract (sensory irritation), whereas long-term exposure to certain pollutants may result in more severe effects like asthma or cancer.

The indoor environment plays a substantial role in terms of exposure to airborne pollutants, because people spend most of their time indoors, where pollutant concentrations are often higher than outdoors (Maroni et al., 1995; Nazaroff and Weschler, 2001). Moreover, people are typically exposed to complex mixtures of volatile organic compounds VOCs, with hundred or more different compounds present in the indoor air.

Schools are of special concern when regarding indoor exposure, because children are particularly sensitive to pollutants and spend a significant amount of time in that environment.

In a recent case, health problems were reported in a French school. The symptoms were non-specific (like irritation of the eyes and airways). The hypothesis was formulated that these symptoms might be related to exposure to airborne pollutants. In order to test this hypothesis, a comprehensive measurement protocol was established for the building and numerous airborne compounds were identified and quantified. Based on these results, the risk of developing the described health effects (sensory irritation) due to the pollutants was assessed. These experiences are reported here, and the present paper may serve as an example on how to carry out risk assessments of sensory irritants in indoor air.

2. The Case

Building: The school – with approximately 80 children and 5 permanent staff – is situated in a small French town within a residential area. It is surrounded by a schoolyard, another school, a small storehouse, and a football ground. The building was constructed about 40 years ago. The site has no industrial history. The building itself consists of three classrooms, a dormitory, a kitchen, a hall, an office, a library, and a storage room. There is no ventilation system installed. The building was carefully inspected with regard to potential chemical and biological emission sources (furniture, household products, water damage, moisture etc.), but no relevant sources were identified.

Health Symptoms: At first, some of the teachers complained about non-specific symptoms like dry sensation of the eyes, irritation of the upper respiratory tract, headaches, and a rough tongue. Later on several children complained about similar problems. The symptoms occurred in different rooms and at different times of the day, but not every day. A correlation with a specific activity inside or outside the building could not be established. Teachers and pupils in the other school nearby (within 50 m distance) did not complain about similar symptoms.

3. Sampling Strategy

Based on the reported health problems, known sensory irritants (aldehydes, organic acids, and the inorganic compounds SO_2 and NH_3) were measured in the air. Additionally, the presence of other VOCs was verified.

Symptoms occurred over relatively short time periods. For this reason, air samples were taken – whenever possible – during episodes when symptoms occurred, either by using online monitoring techniques, or by using grab samplers (canisters). Passive samplers were used in order to sample over an extended period of time. The latter technique does not allow for identifying peak concentrations, but high average concentrations may indicate that episodes with high concentrations occurred.

Samples were taken either in most of the rooms (passive samplers) or in the classroom where the highest number of complaints were reported.

As a reduced relative humidity RH may contribute to eye and airway irritation, RH was hence measured as well.

<Table 1 should be placed here. >

4. Methods

Aldehydes: Passive sampling devices (Radiello®, Fondazione Salvatore Maugeri, Padova, Italy (Cocheo et al., 1996)) equipped with dinitrophenyl hydrazine (DNPH) sampling cartridges and ozone scrubbers (Bates et al., 2000), were used to quantify concentrations of the compounds listed in Table 1.

After exposure, the sampling cartridges were extracted with 2 ml acetronitrile. The extracts were analysed with HPLC separation (KROMASIL C18 150 mm- 3mm - 3.5 μm) and UV detection (λ=365 nm).

The samplers were installed in the classrooms and outdoors (for comparison), and left exposed during 5 days.

Organic Acids: Approximately 1 m^3 air was drawn through 50 ml of 0.1 N NaOH in order to sample the organic acids listed in Table 1. Compounds were quantified by HPLC separation (analytical column AIT REZEC ACIDE ORGANIQUE 300 mm) and UV detection (wavelength $\lambda = 210$ nm).

Due to a limited number of sampling devices, these compounds were sampled only in the classroom where most of the complaints were reported, and outdoors (for comparison).

Volatile Organic Compounds: Other VOCs than aldehydes and organic acids may be responsible for sensory irritation. For this reason, an evacuated grab sampler (passivated Restek® canister) was left on site. The sampler was filled with air during a period when health problems occurred, so that potential sensory irritants were trapped. A fraction (2 L) of the sampled air was then transferred onto a sorption tube (Carbotrap) and analysed by thermodesorption and GC-MS (column DB30, 30m; thermodesorption at 350°C during 5 min).

Inorganic compounds: SO_2 was continuously monitored with a UV fluorescence analyser (megatec model 43C) during two days in a classroom where an increased number of complaints had been reported.

Ammonia was sampled on a solid adsorbent coated with H_2SO_4 at the same sampling location (sampling volume 30 L, sampling time 10 hours) and analysed by ion chromatography.

Relative Humidity, Temperature: Relative Humidity RH and temperature T were monitored during one week with Tinytalk® measurement devices.

5. *Toxicological Reference Values and Additivity of Effects*

A pollutant at a concentration below its Toxicological Reference Value (TRV) is not considered to represent a risk for the health endpoint studied. Methodologies are available for developing such guideline values base on toxicological properties. For example, for noncarcinogen risk characterisation, safety factors can be used that are applied to the lowest observed adverse health effect (LOAEL) or the no-observed adverse health effect (NOAEL) (Anderson and Albert, 1999). Safety factors take into account inter-species differences (when data are based on animal tests) and intra-species differences (to take into account differences in sensitivity). Other safety factors can account for differences in exposure time (workplace and indoor environment) (Nielsen et al., 1998).

In the present paper, TRV will be selected or developed based on the symptoms of sensory irritation. These symptoms are probably related to short-term (or acute) exposure.

Acute exposure is usually associated with exposure times between a few minutes and several days.

When dealing with effects of irritation of the upper respiratory tract, values based on a mouse bioassay have been suggested to predict toxic properties of chemicals (Alarie, 1973). The RD_{50} i.e. the concentration inducing a 50% decrease in 10 minutes in respiratory rate in mice (found by extrapolation if necessary) is used as a base for comparing irritating potencies of chemicals. It was shown that slight irritation can occur at 0.1 x RD_{50}, and minimal or no effect would occur at 0.01 x RD_{50}. In practice, 0.03 x RD_{50} has been recommended as a guideline for occupational exposure limits.

In the present case, internationally accepted guideline values (WHO-OMS, 2000) for short-term exposure are chosen as TRV whenever available. This was the case for formaldehyde and SO_2. Alternatively, guideline values proposed by the Nordic Committee on Building Regulations are applied (Nielsen et al., 1996; Nielsen et al., 1998) (organic acids, propanal, butanal, hexanal, octanal, and ammonia).

Finally, tentative TRV are derived by dividing 0.03 x RD_{50} values by 10 (sensitive population) for pollutants where neither international nor national guideline values are available (acetaldehyde, pentanal, heptanal).

Table 1 summarises the guideline values (TRV) for the studied compounds.

Indoors, persons are typically exposed to mixtures of pollutants. Irritating effects of different compounds may possibly be additive at the low concentrations frequently encountered indoors. This assumption is supported by animal studies where irritating effects of mixtures of aldehydes at low concentrations were examined (Flemming et al., 1996).

According to this assumption, the resulting effect of a mixture may be expressed as a weighted sum parameter S (Equation 1), which contains the sum of pollutant concentrations c_i divided by their corresponding TRV_i, expressing their irritation potential.

$$S = \frac{c_1}{\mathrm{TR}V_1} + \frac{c_2}{\mathrm{TR}V_2} + \frac{c_3}{\mathrm{TR}V_3} \ldots < 1 \qquad (1)$$

If the weighted sum parameter S is less than 1, it is reasonable to assume that complaints about sensory irritation are not due to the presence of the compounds included in the studied mixture. Note however that S can also exceed 1 even when individual pollutant concentrations remain below their guideline values.

6. Results and Discussion

Relative humidity ranged between 28 and 49 % (average 38%) and remained for several days below the values recommended for a good indoor air quality (40-50% RH). Pollutant concentrations for different sampling locations are summarised in Table 2. When only single spot measurements are available (e.g. organic acids), the results are considered to represent concentrations in all the sampling locations. Results are now compared with literature data and guideline values (Table 1).

< Table 2 should be placed here. >

Average aldehyde concentrations agree well with existing literature data , and do not exceed their TRV in any case.

Organic acid concentrations are slightly above literature data, but remain below their TRV.

Average SO_2 concentrations are higher than concentrations presented in the literature. Continous monitoring allowed for measuring SO_2 during the occurrence of health complaints, but no peak concentrations were observed. SO_2 concentrations remained below the TRV.

Ammonia concentrations remained below the TRV and are comparable to literature data.

<Table 3 should be placed here.>

Other VOCs that were detected during a period with health complaints are summarised in Table 3 with relative intensities (relative to the most intensive peak) of the major constituents. A profile of compounds typically found indoors is obtained (Brown et al., 1994; Maroni et al., 1995). The identified compounds are not considered as particularly high sensory irritants.

7. Risk Assessment

The fundamental assumption of the sampling strategy consists in the fact that measured concentrations represent maximum concentrations to which all individuals can be exposed in all locations and at all times in the school. If this assumption is true, then the risk of developing sensory irritation due to the presence of the studied compounds can be assessed as negligible. This holds both for individual compounds (concentrations remain below the respective TRV) and for the mixture of studied compounds, as the weighted sum parameter S (Table 2) ranges between 0.2 and 0.5 and is hence less than 1.

8. Conclusions

The risk assessment of airborne sensory irritants present in the school leads to the conclusion that reported health complaints are not due to the presence of the measured compounds.

However, several aspects should be taken into account in this context:

- The adopted sampling strategy may not be appropriate, since sampling time and location may not coincide with time windows and places where peak concentrations occurred. Online monitoring in all locations and of all potential sensory irritants would be necessary. This represents a challenge in terms of equipment and time, and online monitoring techniques are not available for all the compounds considered.

- With the existing sampling and analytical techniques it is not possible to sample, identify and quantify all sensory irritants which may be present in the air. In particular reactive compounds with one or more functional groups are rarely detected indoors, because of their short lifetime, and because conventional sampling and analytical techniques are not appropriate (Wolkoff et al., 1997; Wolkoff and Nielsen, 2001). New sampling and analytical techniques need to be developed.

- A reduced relative humidity and inadequate fresh air in the building may contribute to sensory irritation. Psychosocial factors can also play an important role in the given context: increased attention from authorities, the presence of 'experts' and sampling equipment, and a strong group behaviour will result in individuals paying much more attention to any health effect related to sensory irritation.

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Table Captions

Table 1: Target compounds, Toxicological Reference Values TRV and typical indoor concentrations. The TRV for heptanal is an estimate based on the TRV of its homologue pentanal. All TRV are rounded up in order to illustrate their approximate nature.

Table 2: Concentrations outdoors and in different sampling locations and weighted sum parameter S ($\mu g/m^3$). Organic acids and inorganic compounds were only measured in one classroom, these concentrations were hence extrapolated to other rooms

Table 3: Identified VOCs sampled during a period with sensory irritation (intensity relative to most intensive peak); +++ high intensity; ++ intermediate intensity; + low intensity

compound	CAS	guideline value ($\mu g/m^3$) / duration	indoor air concentration range ($\mu g/m^3$)	reference
		WHO (WHO-OMS, 2000)		
formaldehyde	50-00-0	100 / 30 min	6-127	(Meininghaus et al., 2001)
SO_2	7446-09-5	500 / 10 min	3-12	(Chao, 2001)
		Nordic Committee on Building Regulations (Nielsen et al., 1996; Nielsen et al., 1998)		
formic acid	64-18-6	2000	19 – 34	(Reiss et al., 1995)
acetic acid	64-19-7	2500	39 –72	(Reiss et al., 1995)
propionic acid	79-09-4	3000	--	
butyric acid	107-92-6	4000	--	
propanal	123-38-6	4000	3-5	(Reiss et al., 1995)
butanal	123-72-8	3000	1-2	(Reiss et al., 1995; Ullrich et al., 1999)
hexanal	66-25-1	3000	3-92	(Meininghaus et al., 2001)
octanal	124-13-0	4000	1.5-29	(Meininghaus et al., 2001; Ullrich et al., 1999)
NH_3	7664-41-7	4000	0-423	(Gomzi, 1999)
		Tentative		
acetaldehyde	75-07-0	20000	3-86	(Meininghaus et al., 2001; Williams et al., 1996)
pentanal	110-62-3	12000	1-6	(Meininghaus et al., 2001)
heptanal	111-71-7	12000 (estimate)	3-17	(Meininghaus et al., 2001)

	Concentrations of sensory irritants in different locations (µg/m^3)						
	outdoors	dormitory	class I	class II	class III	hall	office
Formaldehyde	2	20	22	25	23	22	23
Acetaldehyde	2	6	6	7	6	6	7
Propanal	-	-	-	-	-	-	-
Butanal	-	4	3	4	4	3	6
Pentanal	-	-	-	-	-	-	-
Hexanal	1	6	8	11	7	4	5
Heptanal	-	-	-	-	-	-	-
Octanal	1	4	-	-	1	-	1
formic acid	55	26	26	26	26	26	26
acetic acid	-	65	65	65	65	65	65
Ammonia	312	312	312	312	312	312	312
SO_2	42	42	42	42	42	42	42
sum *S*	**0.2**	**0.4**	**0.4**	**0.5**	**0.4**	**0.4**	**0.4**

compound	intensity
benzene	+
toluene	++
2 ethyl hexanol	+++
ethyl hexanoic acid	++
ethyl benzene	+
xylenes	+
terpenes	+
phenol	+
dichlorobenzene	+